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(54) **Radio telephone system using a variable length training sequence.**

(57) In radio phone systems with a digital cellular design currently used a training sequence of constant length, consisting of an guard part and a reference part, is included in a transmission burst between a base station and a mobile station. With the aid of a received training sequence, the receiver calculates the impulse response of the channel and is thereafter adapted into the channel. The quality of the connection can, according to the invention, be enhanced in that the training sequence is made adaptive, whereby the lengths of the guard part and the reference part may vary while the total length of the training sequence remains the same. According to another embodiment, also the total length of the training sequence is changed.

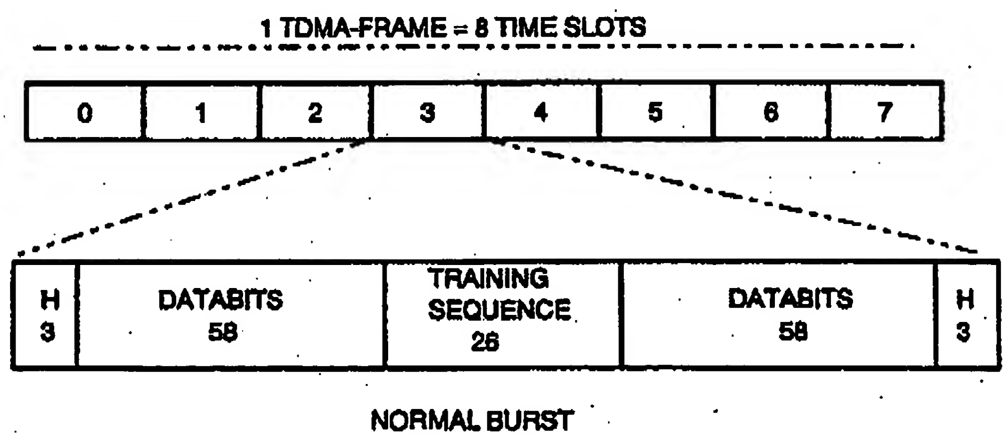

Fig. 2

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The present invention relates to a radio telephone system provided with at least one base station and a plurality of subscriber apparatus, and in which in a radio channel between the base station and a subscriber apparatus a training sequence is transmitted in a transmission burst, according to which the receiver fits the channel equalizer into the radio channel.

Many information transmission problems in the radio phone system involve time-variant or statistical sources of signal degradation in a radio channel. An advantage of a digital radio telephone system compared with an analog one is that it can be designed to monitor a channel and be adapted to changes thereof. Any transmission channel, be it a transmission line or a radio channel, affects the amplitude of the waveform, frequency or phase of the signal, thus producing intersymbol inteference among the bit pulses. In a mobile station, like a radio phone in a car, the characteristics of the channel change constantly over time. A general solution in digital cellular systems known in the art is to use adaptive channel correction. This means that certain distortion characteristics of a channel are measured periodically or continuously, and the predicted distortions in the transmitted pulses are subtracted from the received waveform. The system is capable of monitoring the quality of the channel by measuring the bit error ratio and/or other parameters, such as signal strength and delays.

The subscriber device of the cellular system may be depending on the system, a so-called mobile station, i.e. mobile communicating equipment, having a radio channel provided between the antenna thereof and a base station of the cellular system, or it may refer to a phone which is connected to a remote transmitter/receiver by means of a wire there being a radio channel provided between the antenna of the remote transmitter/receiver and the antenna of the base station. Reference is made below primarily to mobile communicating equipment, though it is useful to note that the same features are applicable to a subscriber device falling within the latter definition as well. The signal strength and the delay are substantially dependent on the signal propagation distance between the base station and the mobile station. As is well known in the art, the transmission rate is high because of the TDMA-transmission typically used in digital systems so that the multiple-path propagation characteristic of the radio path is visible in the reception not only in the form of rapid so-called Rayleigh fading of the envelope of the RF signal but also as an intersymbol interference between the detected bits. In view of the intersymbol interference, the signal propagation model has been so expanded in the digital systems that a received signal is no longer an individual Rayleigh-faded signal but a sum of independently Rayleigh-fading signals and signals including a different delay.

The impulse response of a radio channel can be illustrated in the time domain by means of tap presentation as shown in Fig. 1. Therein, the height of an individual tap illustrates the average strength of a Rayleigh-faded signal and the location of the tap illustrates the transmission delay. The distribution of the taps is dependent on the power levels used and the enviroment conditions, and the fading frequency of the taps is dependent on the speed of the mobile station, e.g. of a car. In various systems, some of such propagation models have been defined in order to illustrate various enviroments and vehicle velocities.

Due to the fact that the radio channel changes rapidly, it is advantageous if the intersymbol interference of the detected bits caused by signal transmission across the radio channel is corrected by measuring the impulse response of the channel and by adapting the receiver to the tap configuration of the channel. This is usually carried out in the systems so that the base station or the mobile communicating equipment transmits a known bit configuration in a transmission burst thereof, e.g. a constant-length sequence of consecutive bits. The sequence is called a training sequence. The receiver typically would have earlier received an encoded piece of information about what kind of bit pattern, that is training sequence, will be transmitted. The receiver correlates the known training sequence with the corresponding training sequence it received and equivalent to the encoded data accessed from the memory. As a result of the correlation, an estimate on the radio path (i.e. delay) is received and the receiver sets the channel equalizer so that the delay distributions are corrected on a given length. For instance, in the GSM system the delay distributions are corrected up to 16 μs.

One TDMA frame, for instance in the GSM system, comprises eight time intervals. The signal is transmitted in the form of bursts, of which a so-called standard burst is shown in Fig. 2. It consists of a first three tail bits, whereafter 58 data bits follow, said bits containing data or speech. They are followed by a training sequence of 26 bits in length, then again followed by 58 data bits, and finally, by three tail bits. Between the time intervals of the frame a 8.25 sec a guard period is provided. As shown in Figure 2, the training sequence is located in the middle of a burst as a uniform sequence, its constant length being 26 bits. Eight training sequences differing in bit configuration are provided, and pre-information has been transmitted to the phone about the type of training sequence to be transmitted by the base station.

The training sequence need not be located in the middle of a burst. For example, in a digital radio phone system used in the USA a frame consists of six time intervals, each containing 162 symbols. One symbol may comprise 2 bits, as in the QPSK modulation used in said system, or even more bits, depending on the modulation system. In a burst to be transmitted from a base station to a mobile station, a transmission time interval always contains a first 14 symbol synchronization burst used as a training sequence. Let it be noted that the

length of a training sequence is constant. In said system six different sequences of training sequences are provided.

Let it be noted that the training sequence is transmitted both from the subscriber device to a base station (Up Link) and from the base station to the subscriber device (Down Link). The symbol sequences of the training sequences need not necessarily be the same in both directions. Whatever the system, endeavours are made to provide such sequences of training sequences that they are provided with as good autocorrelation properties as possible, i.e. on both sides of a peak in the middle of an autocorrelation function a sufficient amount of zeroes are provided. A given training sequence is appropriate for a given environment. For instance in city areas the multiple path propagation of a signal dominates and the training sequence can therefore be different from that in the countryside where few obstacles causing signal reflections exist. In systems currently used the length of a training sequence is a constant length typical of the system and it has been selected according to the so-called worst case, whereby it is necessary to be prepared to correct the delay distortion time-wise over a long distance and it is assumed that the impulse response of the channel is multiple-tap type.

Fig. 3 shows the design of a typical training sequence. The example is selected from the GSM system. The training sequence comprises a reference part, on both sides whereof there being an additional part. The length of the reference part is 16 bits, and the length of each guard part is 5 bits. The shape of a training sequence is thus 5+16+5. Fig. 4 shows the bit sequences included in the training sequences used. As mentioned above, the sequences have been so selected that they are provided with good autocorrelation properties. The length of the guard part determines how long an impulse response in said training sequence is estimatable. In the present training sequence a six-tap impulse response can be estimated. The length of the additional part in GSM has been selected to conform to the worst instance, i.e. training sequences similar in configuration are used all over the network, although not all six taps need to be estimated: if the delay distribution is small, as it is in the countryside with a rather even scenery, estimation of only a few taps would be enough.

The guard part need not be located on both sides of the reference part, such as in the GSM system, instead, it can be only one guard part which is located before or after the reference part. In practice, the guard part is so produced that the first and/or last symbols are selected for the symbols thereof.

The length of the additional parts of the training sequence and the reference part is significant in that the longer the reference part (the more bits or symbols), the better channel estimate is obtained because when using a long reference part the noise becomes averaged, thus not distorting the result. On the other hand, the longer the guard part (as symbols or bits), the longer bit distributions can be measured. Now, reservations have been made e.g. in the GSM system against the most difficult instance by setting 5 bits for the length of the additional part, whereby a six-tap impulse response can be estimated.

Setting the reference part and the guard part fixed in length involves certain drawbacks. If the multipath propagation is insignificant, i.e. the impulse response of the channel is short in duration, it is of no use to utilize a long additional part, and instead, a long reference part would be preferred, whereby a better estimate of the radio channel could be obtained. Thus, in areas where no obstacles exist to a disturbing degree, a good quality of the connection could be provided also in long distances. On the other hand, in areas where the multiple-path propagation is dominant, it would be better use as long additional part as possible, whereby a multiple-tap impulse response would be provided and a channel equalizer can be disposed to correct the delay distribution time-wise on a great distance. In favourable conditions the length of the entire training sequence need not be very long. In such a system, capacity would be released in the burst to transfer more speech and data information.

According to the present invention there is provided a radio telephone system comprising at least one base station and at least one subscriber equipment and capable of forming a radio communication channel between the base station and subscriber equipment, and means for determining an impulse response of the radio communication channel, the radio communication channel including a training sequence in transmission bursts between the base station and subscriber equipment, and said training sequence comprising a reference part, at least one guard part and at least one additional part, wherein the respective lengths of the reference part, the guard part and the additional part are variable dependent upon the impulse response of the radio communication channel.

This has the advantage that the length of the training sequence can be optimised for different impulse responses of the radio communication channel.

Embodiments of the invention are described below by way of example only and with reference to the accompanying drawings, in which:-

Fig. 1 illustrates the impulse response of a received radio channel in time domain, so-called tap-type presentation,

Fig. 2 is a standard burst in the GSM system,

Fig. 3 is a typical structure of a training sequence,

Fig. 4 presents bit sequences of a training sequence in the GSM system,

Fig. 5 provides some examples of adaptive sequences.

In accordance with a first embodiment of the invention, the training sequence can be of a fixed length while the lengths of the guard part and the reference part vary from situation to situation. For example, when the impulse response of a channel is short such that the required guard part is also short, or the signal - noise ratio of the channel deteriorates, the reference part can be lengthened at the cost of the additional part, whereby a better estimate about the radio channel can be made. Alternatively, if the impulse response of the channel in the area of a cell is long or if it becomes longer, the guard part is lengthened at the cost of the reference part. An advantage of a training sequence of a fixed length is that the burst remains constant in length and shape. Let us assume that the length of a training sequence is a constant 30 symbols. A sequence could be of form 7+16+7 (i.e. guard part + reference part + additional part) when the impulse response of the channel is long. With such configuration, not more than eight taps can be estimated. When the impulse response of the channel is shorter, the training sequence could be 5+20+5 or 3+24+3, or even 1+28+1 in form, depending on the number of bits required. In the Table of Fig. 5 more examples are presented on adaptive sequences. The "Exemplary sequence" on the left in the table is used e.g. when the impulse response is long, and the "adaptive" sequence can be transmitted when the impulse response is short, so that the length of the reference part can be increased at the cost of the additional part, and a better estimate on the channel can be provided. It should be noted that the binary sequences presented here are merely exemplary in character.

A second embodiment in accordance with the invention provides a training sequence in which the total length is not constant but varies. In situations in which the impulse response is short or it becomes shorter, and a good channel estimate with a short guard part can be produced, the guard part can be reduced while the reference part remains the same in length. If the length of a training sequence becomes shorter, the symbols previously therefor can be used for other purposes, for instance speech/data transfer of the user, or for transferring of signalling data. Similarly, in adverse situations in which the impulse response of the channel is very long or it becomes longer, the training sequence can be lengthened by lengthening the additional part, whereby by means of the long additional part, a long delay distribution can be taken into consideration. If no essential changes occur in the impulse response of the channel, the signal / noise ratio of the channel gets worse, the length of the reference part is increased so that a better estimate on the channel can be made and the signal / noise ratio is enhanced. Respectively, together with the improved signal / noise ratio, the reference part can be shortened. In said two last-mentioned instances, the length of the guard part will not be changed, but along with the changing length of the reference part the total length of the training sequence changes.

A variation of the total length of the training sequence in accordance with the second embodiment can be implemented in the systems known in the art, e.g. by varying the length of the time interval in which the training sequence is transmitted, whereby an increase in the length of the training sequence is not carried out at the cost of the rest of symbols of the transmission burst. Another form of embodiment is such that the training sequence can be extended to the range reserved for the speech / data symbols of the data field, provided there is room for them at that moment. Also the modulation system utilized has an influence on how many bits can be transmitted in a given number of symbols; therefore, when the modulation method is changed, also the number of the bits available for a training sequence is also affected.

All of the embodiments include the possibility that the training sequence can be transmitted only every now and then, not in each frame. Thus, instead of transmitting the symbols of a training sequence, user information (speech / data) or system data can be transmitted. The second embodiment makes the possibility feasible that the training sequence can be reduced to zero, whereby it will not be transmitted.

Various ways for transmitting an adaptive training sequence can be adopted. First, the operator can measure the environment of the cell and define what kind of training sequence is most appropriate and use it. When a connection is produced between a base station and a mobile station, the base station transmits information, by using e.g. some method known in the art, about which type of training sequence is in use for said training sequence. The training sequence information may also not be transmitted, whereby the mobile station tests what kind of training sequence is most appropriate for the received training sequence, and makes a decision of using it. The same training sequence is in use in the cell area. Secondly, a connection-specific training sequence can be used. It can be implemented so that right at the beginning of a connection a long training sequence is used (according to the worst instance). Thereafter, the base station changes the training sequence by changing the length of the reference part, the length of the additional part, the total length of the training sequence, or a combination thereof. Information about a change of the training sequence is transmitted to the mobile station. Thus, the base station selects the best training sequence available for said connection, and from that moment onwards, the most appropriate training sequence is used. In practice, such method may, for instance, be adopted that an appropriate length of the guard part is concluded e.g. on the basis of the impulse response of the channel measured by the subscriber device. When the training sequence is transmitted

from a base station to a subscriber device, the subscriber device measures the impulse response of the channel. If it finds out that the guard part is unneccessarily long or too short, it informs the base station thereof, whereby the training sequence is equally changed.

The aim of the adaptive training sequence described above is to provide as good channel estimate as possible for the radio link to be used, but the invention may equally be used for achieving a good synchronization, because if the mobile station is adapted as well as possible into the channel, also a good synchronization is achieved, in addition to a correction of the delay distribution and the correct channel estimation.

In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

The scope of the present disclosure includes any novel feature or combination of features disclosed therein either explicitly or implicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed by the present invention. The applicant hereby gives notice that new claims may be formulated to such features during prosecution of this application or of any such further application derived therefrom.

Claims

1. A radio telephone system comprising at least one base station and at least one subscriber equipment and capable of forming a radio communication channel between the base station and subscriber equipment, and means for determining an impulse response of the radio communication channel, the radio communication channel including a training sequence in transmission bursts between the base station and subscriber equipment, and said training sequence comprising a reference part, at least one guard part and at least one additional part,, wherein the respective lengths of the reference part, the guard part and the additional part are variable dependent upon the impulse response of the radio communication channel.

2. A radio telephone system according to claim 1, wherein the total length of the training sequence is constant.

3. A radio telephone system according to claim 2,wherein the guard part of the training sequence is lengthened at the cost of the reference part when in the range of a cell the impulse response of the channel is relatively long.

4. A radio telephone system according to claim 2, wherein the reference part is lengthened at the cost of the additional part when the impulse response of the channel is short or the signal / noise ratio of the channel deteriorates,

5. A radio telephone system according to claim 1,wherein the total length of the training sequence is variable.

6. A radio telephone system according to claim 5, wherein the total length of the training sequence is increased by increasing the guard part when the impulse response of the channel is relatively long.

7. A radio telephone system according to claim 5 or claim 6, wherein the total length of the training sequence is increased by increasing the reference part when the signal / noise ratio deteriorates.

8. A radio telephone system according to claim 5, wherein the total length of a training sequence is reduced by reducing the guard part when the impulse response of the channel is relatively short, thereby increasing the number of information bits available in the radio communication channel.

9. A radio telephone system according to claim 5 or claim 8, wherein the total length of a training sequence is reduced by reducing the reference part when the signal / noise ratio of the channel improves, thereby increasing the number of information bits available in a transmission burst.

10. A radio telephone system according to any one of the preceding claims, wherein the additional parts of the training sequences and the reference parts are respectively of equal lengths in each radio communication channel formed between the base station and the subscriber device for a particular cell.

11. A radio telephone system according to any one of the preceding claims, wherein both the length of the guard part and the length of the reference part are connection-specific.

12. A radio telephone system according to any preceding claim, wherein the training sequence is not always transmitted during a transmission burst.

13. A radio telephone system according to claim 8 or 9, wherein the length of a training sequence has been reduced to zero.

14. A digital cellular system, comprising several base stations and subscriber equipment, and in which between the base station and a subscriber equipment a radio channel can be produced, in which channel a training sequence recognized in symbol sequence by the receiver unit is included in the transmission burst, said sequence consisting of a reference part and at least one additional part, determining how long impulse response of the radio channel can be measured, whereby the receiver fits in the radio channel being used according to the impulse response measured in the radio channel, characterized in that the guard part and the reference part of the training sequence are variable in symbol length.

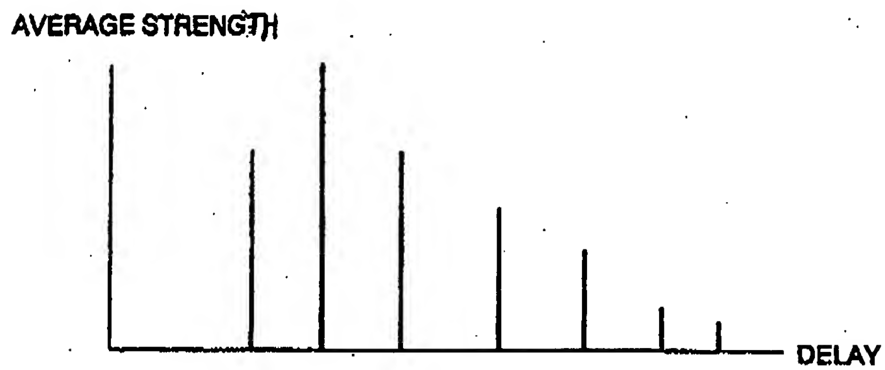

Fig.1

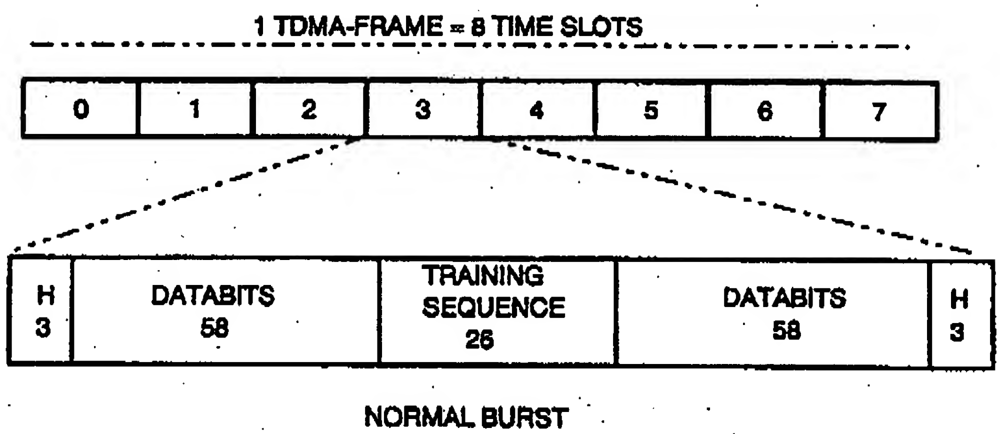

Fig. 2

Fig. 3

Training sequence	Bits of training sequence		
code	Guard part	reference part	Guard part
0	0.0.1.0.0	1.0.1.1.1.0.0.0.0.1.0.0.0.1.0.0	1.0.1.1.1.
1	0.0.1.0.1	1.0.1.1.1.0.1.1.1.1.0.0.0.1.0.1	1.0.1.1.1.
2	0.1.0.0.0	0.1.1.1.0.1.1.1.0.1.0.0.1.0.0.0	0.1.1.1.0.
3	0.1.0.0.0	1.1.1.1.0.1.1.0.1.0.0.0.1.0.0.0	1.1.1.1.0.
4	0.0.0.1.1	0.1.0.1.1.1.0.0.1.0.0.0.0.0.1.1	0.1.0.1.1.
5	0.1.0.0.1	1.1.0.1.0.1.1.0.0.0.0.0.1.0.0.1	1.1.0.1.0.
6	1.0.1.0.0	1.1.1.1.1.0.1.1.0.0.0.1.0.1.0.0	1.1.1.1.1.
7	1.1.1.0.1	1.1.1.0.0.0.1.0.0.1.0.1.1.1.0.1	1.1.1.0.0.

Fig. 4

Exemplary sequence	Respective adaptive sequence
5+16+5 10111 0010 0000 1101 0111 00100	3+20+3 001 0001 0111 1001 1010 001 000
7+16 1010111 0010 0000 1101 0111	3+20 001 0001 0111 1001 1010 0001
20+9 0001 0111 1001 1010 0001 000101111	24+5 0110 1000 0001 1001 0101 1110 01101
20+9 0001 0111 1001 1010 0001 000101111	28+1 0011 0101 1111 0001 0010 1000 00110

Fig. 5

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 1611

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, vol.40, no.2, May 1991, NEW YORK US pages 392 - 404, XP234902 G.D ARIA ET AL. 'FAST ADAPTIVE EQUALIZERS FOR NARROW-BAND TDMA MOBILE RADIO' * abstract * * page 393, right column, line 4 - line 24 * * figure 1 *	1,14	H04B7/005
A	EP-A-0 332 302 (NCR CORPORATION) * page 3, line 46 - page 4, line 58 * * page 8, line 19 - line 31 * * tables 1,2 *	1,14	
A	PROCEEDINGS OF 41st IEEE VEHICULAR TECHNOLOGY CONFERENCE 19-22 May 1991, St. Louis (US) NEW YORK (US) pages 13-16, T.NAKAI ET AL. "ADAPTIVE EQUALIZER FOR DIGITAL CELLULAR RADIO" * abstract * * page 14, left column, line 1 - line 6 * * page 14, right column, line 3 - page 15, left column, line 29 * * figure 1 *	1,14	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H04B H04L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 June 1994	Lydon, M

CATEGORY OF CITED DOCUMENTS

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